Salt International Collaborations FY21 Update

Spent Fuel and Waste Disposition

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology

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July 31, 2021

M3SF-21SN010303062 SAND2021-9232R

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SUMMARY

This report summarizes the international collaboration work conducted by Sandia and funded by the US Department of Energy Office (DOE) of Nuclear Energy Spent Fuel and Waste Science & Technology (SFWST) as part of the Sandia National Laboratories Salt R&D and Salt International work packages. This report satisfies the level-three milestone M3SF-20SN010303062. Several stand-alone sections make up this summary report, each completed by the participants. The sections discuss international collaborations on geomechanical benchmarking exercises (WEIMOS), granular salt reconsolidation (KOMPASS), engineered barriers (RANGERS), and model comparison (DECOVALEX). Lastly, the report summarizes a newly developed working group on the development of scenarios as part of the performance assessment development process, and the activities related to the Nuclear Energy Agency (NEA) Salt club and the US/German Workshop on Repository Research, Design and Operations.

All the work summarized in this annual update has occurred during the COVID-19 pandemic, and therefore no international or domestic travel has occurred. All the collaborations have been conducted via email or as virtual meetings.

CONTENTS

ACRONYMS

BATS	brine availability test in salt
BGE	Bundesgesellschaft für Endlangerung
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
COVID-19	coronavirus disease of 2019
DECOVALEX	Development of Coupled models and their Validation against Experiments
DGGT	Deutsche Gesellschaft für Geotechnik
DOE	Department of Energy
DOE-EM	DOE Office of Environmental Management
DOE-NE	DOE Office of Nuclear Energy
DRZ	disturbed rock zone
ELSA	Schachtverschlüsse für Endlager für hochaktive Abfälle
FEP	feature, event, process
FY	fiscal year (October to September)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit
HLW	high-level waste
IfG	Institut für Gebirgsmechanik GmbH
IGSC	international group for the safety case
KOMPASS	Compaction of Crushed Salt for Safe Enclosure (English translation of German acronym)
KOSINA	Konzeptentwicklung für ein generisches Endlager für wärmeentwickelnde Abfälle in flach lagernden Salzschichten in Deutschland sowie Entwicklung und Überprüfung eines Sicherheits- und Nachweiskonzeptes
M-D	Munson-Dawson
NEA	Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
RANGERS	Entwicklung eines Leitfadens zur Auslegung und zum Nachweis von geo-technischen Barrieren für ein HAW Endlager in Salzformationen Design
R&D	Research and Development
RWMC	radioactive waste management committee
SFWST	Spent Fuel and Waste Science & Technology
SNL	Sandia National Laboratories
US	United States
VSG	Vorläufige Sicherheitsanalyse Gorleben
WEIMOS	Weiterentwicklung und Qualifizierung der gebirgsmechanischen Modellierung für die HAW-Endlagerung im Steinsalz
WIPP	Waste Isolation Pilot Plant (DOE-EM site)

SALT INTERNATIONAL COLLABORATIONS FY21 UPDATE

This report is a summary of the international collaboration funded by the US Department of Energy Office of Nuclear Energy Spent Fuel and Waste Science & Technology (SFWST) as part of the Sandia National Laboratories Salt R&D and Salt International work packages for fiscal year 2021 (FY21). Several stand-alone sections make up this summary report, each section completed by different participants. The sections discuss international collaborations on geomechanical benchmarking exercises (WEIMOS), granular salt reconsolidation (KOMPASS), engineered barriers (RANGERS), and model comparison (DECOVALEX). Lastly the report summarizes a newly developed working group on the development of scenarios as part of the performance assessment development process.

Two primary collaborative efforts funded by Salt R&D are co-organization of, and participation in, both the US/German Workshop on Salt Repository Research, Design, and Operation and the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) Salt Club. These meetings were virtual in 2021 because of travel restrictions from the ongoing COVID-19 pandemic. Despite the pandemic, our collaborative efforts have continued, relying on virtual meetings and email for collaboration. We hope to resume periodic in-person meetings with our international colleagues soon.

Because each of the major sections of this report stands alone, each has its own references and conclusions. There is no overall summary or conclusions at the end.

1. International Collaboration through the RANGERS Project

SNL Authors: *Ed Matteo*, *Melissa Mills*, *Rick Jayne*, *Kris Kuhlman*

RANGERS is a collaborative project between Sandia and BGE Technology (including Eric Simo, Phillip Herrold, and Andree Lommerzheim). After translating to English, the acronym means "Design and Integrity Guideline for Engineered Barrier Systems for a HLW Repository in Salt". Geotechnical barriers for a repository in salt formations have already been the subject of numerous research projects. As part of the preliminary safety analysis for the Gorleben site (Vorläufige Sicherheitsanalyse Gorleben – VSG), a verification method for the integrity of sealing elements in a high-level waste (HLW) repository in domal salt formation was developed (Müller-Hoeppe, 2012). This made it possible to carry out a more detailed verification for a shaft closure. In the ELSA (Schachtverschlüsse für Endlager für hochaktive Abfälle) project, a design of shaft closures for HLW repositories was developed (Kudla, 2013). Further research projects such as those reported in (Kudla, 2009) and (Sitz, 1999) investigated different aspects of geotechnical closure systems. Recommendations for the planning and execution of geotechnical barriers were formulated in (DGGT, 2017) by the working group salt mechanics of the DGGT (Deutsche Gesellschaft für Geotechnik – the German Geotechnical Society).

Despite extensive knowledge and experience about geotechnical barriers in salt formations, there is no methodology for the design and verification of such structures for an HLW repository. BGE TEC and Sandia propose to develop jointly a Design and Integrity Guideline for Engineered Barrier Systems for an HLW Repository in Salt in the framework of a joint project between Germany and US. The project aims at developing a guideline for the planning and the design of geotechnical barriers in salt formations. This guideline will serve as a reference manual for the conceptualization of an HLW repository in Germany and the US. It will summarize the current state of art available in two reports and gives an outlook about the technologies which will impact the development of geotechnical barrier systems in the future.

The aim of the project is to develop a guideline for the design and verification of geotechnical barrier systems in repositories in salt formations that incorporates the existing knowledge and experience about geotechnical barriers of BGE and BGE Technology as well as of Sandia and of others. Recommendations for the design and verification of geotechnical barriers based on the state of the art in science and technology will be formulated and an overview of new concepts, building materials and technologies that will shape the state of the art of tomorrow will be given. Four sub-goals are formulated for this purpose:

1. Compilation of existing knowledge and experience for the design and construction of geotechnical barriers and compilation of new concepts and technologies about geotechnical barriers.
2. Development of a guideline based on the state of the art in science and technology for the design and verification of geotechnical barriers.
3. Preliminary design and verification of the geotechnical barrier system for selected repository systems based on the developed guideline.
4. Comparison of design results according to the new guideline with results of previous design and assessment.

The project is divided into six work packages. The outcome of the project KOMPASS – another binational project between Germany and the US – about the compaction of crushed salt as a key element of a sealing system in a salt HLW repository will be exploited in this project.

Overall, significant progress has been made in FY21 in at SNL and BGE. Considerable work has been completed in WP 1 and WP 2. Because the work in subsequent WP's (WP 3 through 6) will be dependent on Performance Assessment (PA) and establishment of a Salt Reference Case, RANGERS has been participating in integration activities with the NEA "Salt Scenarios" workshop. Salt Scenarios brings

together researchers from the US, Germany, Netherlands, and the UK. The salt scenarios workshop benefits both RANGERS and PA-focused DECOLAEX 2023 Task F.

The project presented a poster, oral presentation, and paper at the Waste Management Symposium in 2021. In FY22, RANGERS will have its own DOE-NE milestones.

1.1 (WP 1) State of the Art in Science and Technology

The State of the Art (SOTA) Report will be completed in two stages (SOTA#1 and SOTA #2) and includes

- Extensive description of the state of the art in science and technology for sealing structures: drift seals construction in Asse mine, drift seal prototype at the Morsleben Repository, design and verification of shaft systems of the preliminary safety case of the Gorleben Repository (VSG), shaft seals work done for WIPP, Sandia closure concepts.
- Summary of all relevant findings for the design, construction and integrity verification of sealing structures. Bullets #1 and #2 will comprise the contents of SOTA #1, which will be completed by the end of FY22.
- This work package will also cover the international status of the design and construction of geotechnical barriers that deviate from the approaches currently being pursued in Germany and the US. The research also covers new building materials such as polymer concretes, manufacturability and quality testing, in situ experiments as well as other concepts and technologies such as pre-stressing techniques or thermal elements for faster creep that are relevant for geotechnical barriers. This work will be summarized in the SOTA #2, which will be completed in FY22.

The SOTA Report is nearly complete and consists of activities centered on updating previous reviews and reports of Seal Tests in Salt. By creating a comprehensive review of prominent seal materials (e.g., cementitious materials, crushed salt, and asphalt), the SOTA will provide a firm basis for developing the Design Guidelines in WP 3, 4, and 5.

1.2 (WP 2) Basics and Requirements

- Evaluation and comparison of the regulatory requirements for the design and construction of sealing structures for salt mines and for repositories in Germany and the US
- Determination of site- and repository-specific boundary conditions for the design of sealing structures using the example of repository concepts such as KOSINA and the WIPP.
- Compilation of relevant Features, Events and Processes (FEPs) and scenario developments for geotechnical barriers based on international and national FEP catalogues.
- Compilation of further basics and requirements from the findings of research projects and from practical experience.

Progress has also been made on developing a comprehensive perspective on the Basics and requirements. BGE has generated a seals-focused FEPs analysis that will be cross-checked against previous work on the US-German Salt FEPs Catalogue.

1.3 (WP 3) Development of a Methodology for Design and Verification of Geotechnical Barriers

- Compilation of all components and their functions required for the construction of sealing structures and recommendation for the selection of suitable building materials.
- Development of pre-dimensioning approaches for the design of sealing and shaft closures.
- Review of the technical demonstration concept developed in the scope of VSG for an HLW repository in Germany based on new insights from research projects such as KOSINA and ELSA, the final report of the German Commission for deep disposal of radioactive waste, the planned update of the safety requirements of the German Federal Ministry of the Environment and the characteristics of the different salt formation types.
- Development of a technical demonstration concept based on safety requirements and guidelines in the US.
- Conversion of the FEPs into design loads and resistances as well as design situations according to country-specific guidelines for geotechnical structures.
- Derivation of an overall demonstration framework and the corresponding design situations for the shaft and drift sealing structures.
- Completion of the guideline

1.4 (WP 4) Preliminary Design and Verification of Geotechnical Barrier System

1.4.1 (WP 4.1) Preliminary Design and Verification of Geotechnical Barrier System for KOSINA Concept Based on the Developed Guideline

- Design and preliminary dimensioning of the drift sealing system for a repository concept from KOSINA as an iterative process
- Design and pre-dimensioning of shaft sealing system for a repository concept from KOSINA as an iterative process
- Assessment of the feasibility/constructability of the planned geotechnical barrier system
- Safety demonstration for the derived design situations
- Evaluation of the developed guideline based on the results of the demonstration

1.4.2 (WP 4.2) Preliminary Design and Verification of Geotechnical Barrier System for Generic Heat-Generating Waste Repository in Salt Based on the Developed Guideline

- Design and preliminary dimensioning of the drift sealing system for a generic salt host as an iterative process
- Design and pre-dimensioning of shaft sealing system for a generic salt host as an iterative process
- Assessment of the feasibility/constructability of the planned geotechnical barrier system
- Safety demonstration for the derived design situations
- Evaluation of the developed guideline based on the results of the demonstration

1.5 (WP 5) Comparison of Design Results According to New Guideline with Results of Previous Design and Assessment

In this work package, the Sandia and BGE will compare the design and assessment analysis performed in WP 4 based on the developed guideline with other assessment and performance analyses carried out in previous projects such as VSG, ELSA, and WIPP, and current works for a generic salt repository site. Thus, the benefits and limitations of the guideline will be derived.

1.6 (WP 6) Documentation and Final Report

The outcomes of the project RANGERS will be documented in five reports:

- The first report about the state of the art in science and technology as well as an outlook for new concepts on the design of geotechnical barrier system of an HLW repository in salt rock will cover the work carried out in WP1.
- The elaboration of the guideline will be described in one report. This comprises the work done in WP 2 and WP 3.
- The prototypical design and verification of the geotechnical barrier system will be reported in two reports (WP 4): one for the German case based on a repository concept developed in the scope of the KOSINA project and a second for the American case based on design concept from WIPP to be applied to a generic repository for heat-generating waste in a salt host.
- A synthesis report (WP 6) will close up the project with the main findings and summary and integrated in the comparison carried out in WP 5.

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2. International Collaboration through the KOMPASS Project

SNL Authors: *Melissa Mills*

Joint Project KOMPASS is a collaboration of German and American researchers seeking to improve thermo-hydro-mechanical models for crushed salt (i.e., run-of-mine or granular salt). The project could be characterized as analogous to the preceding Joint Project WEIMOS, but for crushed salt: partners conduct experiments to understand crushed salt behavior and further develop, calibrate, and validate models for crushed salt. After translating to English, the acronym KOMPASS stands for "Compaction of Crushed Salt for Safe Enclosure". The KOMPASS partners are Bundesgesellshaft für Endlangerung Technology (BGE) (Peine, Germany), Institute für Gebirgsmechanik (IfG) (Leipzig, Germany), Technical University of Clausthal (TUC) (Clausthal, Germany), Gesellschaft für Anglagen-und Reaktorsicherheit (GRS) (Köln, Germany), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) (Hannover, Germany), and Sandia National Laboratories (SNL).

The first phase of the KOMPASS project was completed in 2020, with a comprehensive final report produced (Czaikowski et al., 2020). During this phase, experimental techniques for consolidation were thoroughly evaluated to produce adequate pre-compacted and compacted samples under various conditions, which included characterizing sufficient reference material. A total of 34 different samples were produced, and several underwent microstructural investigations to document associated deformation mechanisms.

In addition to laboratory testing and analysis, model benchmarking initiatives revealed that while most models are capable of reproducing results, they still require a well-founded laboratory database to predict functional relationships to further characterize the THM-coupled compaction behavior of crushed salt. The various constitutive model approaches (i.e., C-WIPP, Heeman (BGR), Olivella/Gens (GRS), Callahan (Sandia)) were compared in the first phase to determine the main influencing factors or properties of each and identify specific lab tests needed for sufficient validation.

The second phase of the project officially began in July 2021, with a partner kick-off meeting occurring in September. Based on results from the first phase, a systematic test series has been planned to further establish reproducible and predictable correlations between stress, duration of compaction, moisture states, and respective target porosity. Figure 1 shows the main factors contributing to the behavior of crushed salt and the type of experimental tests needed to improve predictions of those parameters. It is also desired to perform sensitivity analysis across all methods for measuring low porosity (<1% to 5%) and low permeability ($k < 10^{-19}$ m^2) of long-term compacted samples to reduce errors and uncertainties. Sandia plans to contribute to KOMPASS2 by performing additional microstructural investigations on past and future samples, as well as continuing model validation against the expanded experimental results.

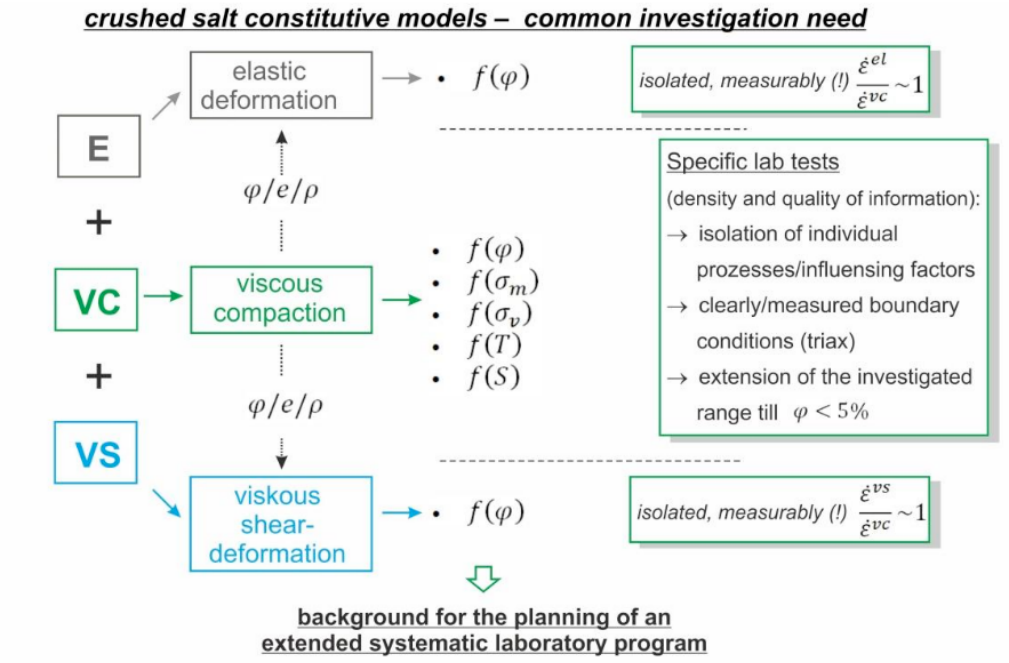

Figure 1. Schematic describing the factors contributing to crushed salt behavior and further laboratory tests needed to evaluate them (Czaikowski et al., 2020).

2.1 Reference

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3. International Collaboration through the Joint Project WEIMOS

SNL Authors: *Benjamin Reedlunn* and *Steve Sobolik*

Joint Project WEIMOS is a collaboration of German and American researchers seeking to improve thermomechanical modeling of salt repositories. The group primarily focuses on improving constitutive models for rock salt, but the partners also undertake extensive laboratory test programs and refine methods for simulating the evolution of underground structures. Typically, the laboratory tests help inform and calibrate the partners' constitutive models, which are then benchmarked against underground experiments and observations. After translating to English, the acronym WEIMOS stands for "Further Development and Qualification of the Rock Mechanical Modeling for the Final High -Level Waste Disposal in Rock Salt". The WEIMOS partners include Hampel Consulting (Mainz, Germany), Institute für Gebirgsmechanik (IfG) (Leipzig, Germany), Leibniz University (Hannover, Germany), Technical University of Braunschweig (TUBS) (Germany), Technical University of Clausthal (TUC) (Germany), and Sandia National Laboratories (SNL). The planned end date for WEIMOS is March 31st, 2022.

The three joint projects that preceded WEIMOS substantially improved the current state-of-the-art models and helped identify the following work packages (WP) that together comprise WEIMOS:

1. Deformation behavior at small deviatoric stresses
2. Temperature and stress dependence of damage reduction and healing
3. Deformation behavior resulting from tensile stresses
4. Influence of inhomogeneities (layer boundaries, interfaces) on deformation
5. Virtual demonstrator

A short description of each work package is given below, followed by three other notes germane to Sandia's participation in WEIMOS and future international collaborations.

3.1 (WP 1) Small Deviatoric Stresses

Salt creep is the driving force for room closure in salt repositories. The precursor to WEIMOS, Joint Project III, confirmed that salt undergoes a creep mechanism change between intermediate and low stresses. Low stress creep occurs below about 8 MPa equivalent shear stress at 60 °C, but methods to accurately measure low stress steady-state creep strain rates, low stress creep's temperature dependence, and the underlying micromechanical mechanism behind low stress creep have not been fully established.

Measurement of low-stress creep is very challenging because the axial strain rates are small, sensitive to small temperature and humidity fluctuations, and can be convolved with volumetric consolidation strain rates. Nevertheless, the IfG has recently developed a test procedure to accurately measure the steady-state strain rate at low stresses. The procedure first involves a long hydrostatic consolidation phase (>100 days) at an elevated temperature (>100 °C). Next, a non-zero, yet low, equivalent shear stress is applied and held constant while the temperature is decreased in a stepwise fashion over a year or more. The high temperatures cause the sample to accrue more creep strain and ostensibly reach the steady-state microstructure more quickly. Once the temperature is once again close to room temperature, the equivalent shear stress is returned to zero to confirm the volumetric strain rate is virtually zero. Finally, the non-zero equivalent shear stress is reapplied to confirm the same axial strain rate is observed. This process has been successfully applied to a WIPP salt sample at 4 MPa equivalent shear stress, and further tests on WIPP salt are underway at 1, 2, 3, 4, 5, and 6 MPa equivalent shear stress.

3.2 (WP 2) Damage Reduction and Healing

Healing of cracks in salt is important for the long-term safety case because cracks in the disturbed rock zone (DRZ), as well as broken pieces of rubble that fall into a room, serve as flow pathways for

radionuclides. Although shear-induced damage has been studied in the past, the influence of temperature and stress state on healing is not well understood. Accordingly, an experimental program is underway at TUC to characterize these dependencies.

Although TUC's preliminary healing tests produced inconclusive results, new high precision equipment combined with innovative testing procedures have produced a clean set of results on Asse salt samples. Some of the WEIMOS partners have simulated these tests and, for the first time, a given model is able to reasonably capture all test results with one unique parameter set. In addition, a new set of healing tests was started on WIPP salt using the same test conditions applied to the Asse salt. Although the WIPP salt creeps and damages substantially faster than Asse salt, the fundamental dependencies on temperature and stress state appear to be the same. Consequently, the partners expect the same model formulation should be able to capture the healing of both salt types with different parameter sets.

3.3 (WP 3) Tensile Stresses

Cracks due to tensile stress can play important roles in creation of the DRZ and subsequent roof fall events, yet limited data exists on tensile failure.

The IfG performed one of the first tensile test studies on WIPP salt in 2019. The cylindrical samples were first damaged (dilated) to different degrees in a triaxial compression cell, and then tensile tested along the cylinder axis to determine the tensile strength. The tensile strengths exhibited a large degree of scatter and did not appear to directly depend on the amount of damage for a given confining pressure. More recently, the TUC performed a similar test series on WIPP and Asse salt. Although Asse salt has fewer impurities than WIPP salt, no clear difference between the two salt types was discernable and no trends could be determined.

The lack of trends may have been caused by orientation of the microcracks induced during the triaxial compression phase. Triaxial compression under low confining pressures causes microcracks that open perpendicular to the subsequent tensile stress axis. Future studies of the tensile strength's dependence on microcracking should attempt to apply tensile stresses that tend to open the microcracks. Unfortunately, such a test program is unlikely to be completed during the WEIMOS project due to limited resources.

3.4 (WP 4) Layer Boundaries

The mechanical behavior of clay seams between layers of salt can substantially affect room closure rates and roof falls, yet experimental data on clay seam behavior does not exist in the literature.

During 2018 through 2020, Sandia sub-contracted RESPEC to perform a series of direct shear tests on natural clay seams extracted from a mine near the WIPP site and artificially manufactured clay seams. The natural clay seam cohesion strength and friction angle were nearly the same as pure salt without any interfaces because salt crystals spanned much of the clay seam interface (Sobolik, 2019). The artificial clay seam cohesion strength and friction angle, on the other hand, were like a saturated, highly consolidated, clay (Sobolik et al., 2020). The behavior of actual clay seams from the WIPP is expected to be somewhere in-between these two bounding cases.

Efforts to obtain actual clay seams from the WIPP have been unsuccessful so far. For example, sliding along Clay G has been observed in the underground, but extracting Clay G cores would require an angled approach because Clay G is close to the drift ceiling on WIPP's upper horizon. Clay F is more easily accessible, but it is a less uniform and distinct layer and not known to slide in the underground. Despite these difficulties, Sandia will continue to investigate ways to procure WIPP clay seams.

3.5 (WP 5) Virtual Demonstrator

The WEIMOS partners are currently at work on two demonstrations of the modeling capabilities developed in the other work packages. One demonstration involves a simulation of unrestrained open drift closure for 30 years, introduction of a sealing system, and continued simulation of the subsequent 70 years. The closure of the open drift exercises low stress creep and tensile damage, while the compaction of the seal deactivates damage evolution and activates healing. The second demonstrator scenario involves a clay seam, an 8×8 m drift, and a 5×5 m parallel drift. Preliminary results show the influence of the low equivalent stress creep, as well as the considerable damage and tensile failures around the larger drift. Further simulations with both demonstration models are in progress.

3.6 New WIPP Core

During 2019 and 2020, Sandia coordinated with the WIPP Test Coordination Office in Carlsbad, the Department of Energy Carlsbad Field Office (DOE-CBFO), and the WIPP Management & Operations contractor, Nuclear Waste Partnership (NWP), to extract 16.5 m of 0.3-m-diameter intact WIPP salt core. The core was shipped to Germany in July and August 2020, amidst COVID-19 restrictions. The core arrived at the IfG and TUC in excellent condition and has been used in various tests over the past year.

3.7 Sandia Constitutive Model Development

Sandia currently utilizes the Munson-Dawson (M-D) model for rock salt, but the M-D model does not include the evolution of damage or healing. It also fails to capture the damage-free mechanical response at moderate strain rates (10^{-6} to 10^{-4} 1/s), which is particularly problematic, as the degree of damage is usually inferred from the difference between the damaged and damage-free behavior. As such, Sandia developed a new constitutive model that captures both damage-free creep tests with slow steady-state strain rates (10^{-11} to 10^{-8} 1/s) and moderate constant strain rate tests (10^{-6} to 10^{-4} 1/s) (Reedlunn, 2020). The model was implemented in Sierra/Solid Mechanics (2021) and the implementation was verified against analytical solutions during the past year. Future work will focus on adding damage and healing to this new constitutive model. These model changes must be completed before Sandia can fully take part in Work Packages 2, 3, and 5.

3.8 Reconstruction of Room Closure Histories at the WIPP

In Joint Project III, the precursor to WEIMOS, the partners compared their model predictions against the closure of WIPP Rooms D and B. Although many aspects of these experiments were thoroughly documented, the digital copies of the closure data were inadvertently destroyed many years ago and the non-trivial process of zeroing and shifting the raw closure measurements after each mining pass was not precisely described. These two issues caused much confusion and correspondence during Joint Project III, so Reedlunn and Williams (2021) located the Room D, B, G, and Q hand-written mining sequence closure measurement data sheets in the WIPP archives, digitized them, reconstructed the closure histories, and documented the process in detail. Most reconstructed closure histories were consistent with previously published results, but two deviations were noted. First, the reconstructed Room Q central station closure histories after 30 days were about 45 % lower than those reported in Munson (1997). Second, the hand-written data sheets found in the WIPP archives extended the Room D and G closure histories by 1.9× and 2.8× beyond those reported in Munson (1997), respectively. Future model validation studies will hopefully benefit from these now well-documented, newly reconstructed closure histories.

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4. NEA Salt Scenarios

SNL Authors: *Kris Kuhlman, Emily Stein* and *Mike Gross*

Personnel from SNL and from Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) have progressed in their long-standing development of a comprehensive Features, Events and Processes (FEPs) catalogue and FEP database to the development of a generalized approach to scenario development for a high-level waste repository at a generic salt site.

The final report on the Salt FEPs project was completed as a Sandia report (Freeze et al., 2020), which is linked to from the NEA Salt Club website. Although it was initially planned for this report to be published as an NEA report, the publication policy of the NEA does not allow re-publishing reports published elsewhere.

An international virtual Salt Scenarios workshop was held via MS-Teams 11-13 August 2020. The workshop had contributions from US, German, UK, and Dutch colleagues and summarized the history of the scenario development process. The scenarios workshop was loosely coordinated with both the development of a salt reference case as part of Task F2 of DECOVALEX 2023, and the discussion of FEPs and modeling associated with the engineered barriers as part of the RANGERS project.

The work that began with the August 2020 Salt Scenarios workshop has continued with several virtual large-group meetings and a small group. The goal of the larger group is to produce an NEA-publishable report summarizing the transition from FEPs to scenarios in several countries. The goal of the smaller group is to draft a journal manuscript on “best practices” in radioactive waste disposal related to scenarios.

4.1 Reference

Freeze, G., S.D. Sevougian, K. Kuhlman, M. Gross, J. Wolf, D. Buhmann, J. Bartol, C. Leigh & J. Mönig, 2020. *Generic FEPs Catalogue and Salt Knowledge Archive*, (151 p.) SAND2020-13186. Albuquerque, NM: Sandia National Laboratories.

5. BATS in DECOVALEX 2023 – Task E

SNL Author: *Kris Kuhlman*

The Brine Availability Test in Salt (BATS) is a field test that is being implemented at the US Department of Energy's (DOE) Office of Environmental Management's (DOE-EM) Waste Isolation Pilot Plant (WIPP) and funded by the DOE Office of Nuclear Energy (DOE-NE) (Kuhlman et al., 2020). This field test is now a task in the 2023 round of DECOVALEX (DEvelopment of COupled models and their VALidation against Experiments). Although all the in-person semi-annual DECOVALEX meetings have been canceled, virtual meetings have allowed teams to make significant progress.

The project began at the virtual project wide DECOVALEX kickoff meeting in April 2020. Teams participating in Task E include: a US team consisting of the organizations conducting the BATS test (Sandia/Los Alamos/Lawrence Berkeley national laboratories), COVRA (Netherlands), RWM/Quintessa (UK), and GRS/BGR (Germany). DECOVALEX and Task E have progressed through three formal virtual semi-annual project meetings. Between each of the formal meetings, three informal Task-E kickoff or status meetings have occurred.

Table 1: High-level DECOVALEX Task E schedule

	Apr.	Nov.	Apr.	Nov.	Apr.	Nov.	Apr.	Nov.
	2020		2021		2022		2023	
Step 0								
Step 1								
Midterm Report → (Nov 2021)								
Step 2								
Step 3								
					Papers and Final Report → (Nov 2023)			

The Task E schedule includes three high-level steps with several sub-steps each:

- Step 0: Single-process H^1 (historical WIPP brine inflow data from horizontal boreholes) and T benchmarks (2020 BATS heat conduction data)
- Step 1: TH^1 benchmark (McTigue thermoporoelasticity solution) & H^2M/H^2 unheated brine inflow test case (two-phase brine initial conditions around the BATS drift)
- Step 2: TH^2M heated brine inflow test case (response of brine production to changes in temperature and stress, and thermal pressurization with two fluid phases)

5.1 References

Kuhlman, K., M. Mills, R. Jayne, E. Matteo, C. Herrick, M. Nemer, J. Heath, Y. Xiong, C. Choens, P. Stauffer, H. Boukhalfa, E. Guiltinan, T. Rahn, D. Weaver, B. Dozier, S. Otto, J. Rutqvist, Y. Wu, M. Hu, S. Uhlemann & J. Wang, 2020. *FY20 Update on Brine Availability Test in Salt*, (107 p.) SAND2020–9034R. Albuquerque, NM: Sandia National Laboratories.

Kuhlman, K., 2020a. *DECOVALEX-2023 Task E Specification Revision 0*, (35 p.) SAND2020–4289R. Albuquerque, NM: Sandia National Laboratories (https://www.osti.gov/servlets/purl/1616375).

6. US/German Workshop and NEA Salt Club

SNL Author: *Kris Kuhlman*

6.1 US/German Workshop

In FY21, the 11th US/German Workshop on Salt Repository Research, Design and Operation is being held virtually (via MS-Teams) distributed over several days throughout the year. The workshop is co-hosted by Wilhelm Bollingerfehr (BGE TECH), Michael Bühler (PKTA), Philipp Herold (BGE TECH), and Kris Kuhlman (SNL).

The first day of the meeting (Tuesday February 2) involved a presentation of the progress and intentions of international radioactive disposal programs in the United States, Germany, the Netherlands, and the United Kingdom.

The second day of meeting (Thursday June 17) was on the topic of granular salt reconsolidation, including presentation of laboratory, modeling, field, and microstructural work in the KOMPASS and GESAV-II projects.

The final two days of the meeting are planned for Wednesday and Thursday 8-9 September. The final days of the meeting will be on the topics of engineered barrier systems (EBS), materials and backfilling, and modeling in salt. The proceedings of the 11th US/German workshop will be prepared after the September meetings.

6.2 NEA Salt Club

The FY20 Nuclear Energy Agency (NEA) 10th Salt Club meeting was held virtually via Zoom on 8 December 2020. At that meeting Kris Kuhlman was elected the new chair and Michael Bühler the vice-chair, replacing Jörg Mönig as Salt Club chair since the beginning of the Salt Club. There was no technical session.

From April 27 to 29, in his first role as Salt Club chair, Kris Kuhlman attended the virtual NEA International Group for the Safety Case (IGSC) meeting, presenting on the ongoing activities of the NEA Salt Club, as the Clay, Salt and Crystalline clubs all exist under aegis of the IGSC, which is itself under the radioactive waste management committee (RWMC).

The 11th NEA Salt Club meeting was held 11-12 May via Zoom. The topical session was performance assessment (PA). The topical session included presentations on geochemistry aspects, scenario development, US PA modeling involved with RANGERS and DECOVALEX Task F, characterization of halite deposits in the UK, and Dutch PA modeling in DECOVALEX Task F.

6.3 FY22 Plans

Next year, both the 12th US/German Workshop and 12th NEA Salt Club meetings are planned to be in-person in Braunschweig, German the week beginning May 9, 2022. This was the planned location of the 2020 US/German Workshop, before it was canceled due to the COVID-19 pandemic.

APPENDIX E

NFCSC DOCUMENT COVER SHEET[1]

Name/Title of Deliverable/Milestone/Revision No. Salt International Collaborations FY21 Update

Work Package Title and Number: Salt International Collaborations – SNL

Work Package WBS Number: SF-21SN01030306

Responsible Work Package Manager: Kris Kuhlman _____ (Name/Signature)

Date Submitted

Quality Rigor Level for Deliverable/Milestone[2]	☐ QRL-1 ☐ Nuclear Data	☐ QRL-2	☒ QRL-3	☐ QRL-4 Lab QA Program[3]

This deliverable was prepared in accordance with Sandia National Laboratories *(Participant/National Laboratory Name)* QA program which meets the requirements of

☒ DOE Order 414.1 ☐ NQA-1 ☐ Other

This Deliverable was subjected to:

☒ Technical Review ☐ Peer Review

Technical Review (TR)
Review Documentation Provided

☐ Signed TR Report or,

☐ Signed TR Concurrence Sheet or,

or,

☒ Signature of TR Reviewer(s) below

below

Peer Review (PR)
Review Documentation Provided

☐ Signed PR Report or,

☐ Signed PR Concurrence Sheet

☐ Signature of PR Reviewer(s)

Name and Signature of Reviewers

HeeHo Park

NOTE 1: *Appendix E should be filled out and submitted with the deliverable. Or, if the PICS:NE system permits, completely enter all applicable information in the PICS:NE Deliverable Form. The requirement is to ensure that all applicable information is entered either in the PICS:NE system or by using the NFCSC Document Cover Sheet.*

- *In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity, along with the Document Cover Sheet, is sufficient to demonstrate achieving the milestone.*

NOTE 2: *If QRL 1, 2, or 3 is not assigned, then the QRL 4 box must be checked, and the work is understood to be performed using laboratory QA requirements. This includes any deliverable developed in conformance with the respective National Laboratory / Participant, DOE or NNSA-approved QA Program.*

NOTE 3: *If the lab has an NQA-1 program and the work to be conducted requires an NQA-1 program, then the QRL-1 box must be checked in the work Package and on the Appendix E cover sheet and the work must be performed in accordance with the Lab's NQA-1 program. The QRL-4 box should not be checked.*